MYME2: a Multi-Payload Integrated Procedure for the Automated, High-Resolution Remote Sensing of Burn Scars

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Abstract – **The most effective, passive remote-sensing methods for detecting and mapping burnt areas rely upon analysis of the behaviour of near-infrared (NIR) and short-wavelength infrared (SWIR) data, with wavelengths between 0.8 and 2.3 μm. As for vegetation fires, the key to effective change detections is to quantitatively distinguish between "at-satellite" reflectance changes - originated by temporary or local image acquisition conditions - and reflectance changes due to the actual vegetation changes in biomass, chlorophyll absorption and water content. We present here a method [1][2] suitable for inter-annual and intra-annual mapping of fires, for winter fire mapping, and for estimation of damage level and vegetation re-growth within burnt areas. The related computing code is referred to as MYME2. Extensive road tests were carried out on ca. 120 images acquired 1996-2004 by Landsat 5-TM, Landsat 7-ETM+, SPOT-4 (both HRVIR-1 and -2) and ASTER. Areas dealt with by the MYME2 demonstration are the whole of Central and Southern Italy (respectively: 2000-2003 and 1996-2004) and the French island of Corsica (2001-2002).**

I. INTRODUCTION

Immediately after a forest fire, the spectral properties of vegetal burnt surfaces are characterised by presence of ash and charcoal in variable percentage depending upon (a) the combustion process, (b) the moisture content, and (c) the fraction and type of biomass originally present on soils.

Basically, ash is a mineral residue, resulting from high fire intensity [3] and complete combustion of vegetals in presence of unrestricted oxygen supply.

Charcoals, conversely, are the typical product of inefficient combustion of biomass under restricted oxygen supply conditions [4]. Charcoals are essentially composed of graphitic carbon.

These two products are the short lived consequence of vegetation combustion. Indeed, weeks or months after a fire (and depending upon meteorological factors and characteristic fuel particle sizes), charcoal and ashes are removed by wind and rainfall, or are covered by newly grown vegetation. This means that, in terms of remote sensing, the spectral separation of burnt and unburnt vegetation decreases with time, after the fire.

From this point onwards, fire effects mark the landscape as geometrical modifications of vegetation structure and abundance, thus being commonly designated as "burn scars". Burn scars (referred to afterwards as BS) present stable spectral signal, but do not keep much of the original extent and characteristics of fire.

Since the regeneration of vegetal biomes with time leads to BS disappearance, it is clear that the remote sensing of BS requires observations frequent enough to cover the whole cycle from immediate post-fire to disappearance of fire effects.

If high-resolution imaging of BS is required, it is mandatory to use satellites in near-polar low Earth orbit, provided with small swaths and loose image refresh rates.

In order to avoid losses of information inherent to overpass frequencies in the order of several weeks, the need of maximising the frequency of observation goes with the need of multi-platform acquisition and, therefore, with that of inter-platform calibration.

We found that cross-rectifying spectral reflectance in different images, at an adequate number of reference points, could be an effective way for singling out the actual vegetation change, whatever the multi-spectral infrared payload. This choice led to dramatically increase the number of multi-spectral satellite scenes that can be successfully injected into a single-step procedure, and to move to a highly automated end-to-end processing cycle. The latter, is based on the extraction of change parameters from the near-infrared (NIR) and the short-wavelength infrared (SWIR) information. In worst cases, when only one or two infrared channels are available, wavelengths immediately below NIR can be also used.

The process, nicknamed MYME2 [1] [2], presents the advantage of improving the robustness of pixel characterisation even in inter-radiometer mode, while keeping light enough to run fast on ordinary workstations.

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The thresholds requirements for a typical processing cycle are 3 infrared bands (NIR or SWIR; exceptionally Red), and three images. The process displays strong improvements in detection capacity with increasing number of scenes and/or infrared channels. However, because of errors inherent to co-registration, precision of the polygons may slightly worsen with increasing number of images.

II. STATE OF ART

A. *Remote sensing data and radiometric corrections*

The principal windows of the electromagnetic spectrum used for land and vegetation analysis are the Visible (0.4 μm to 0.7 μm), the Near Infra-Red (0.7 μm to 1.3 μm, NIR), the Short Wavelength Infra-Red (1.3 μm to 2.5 μm, SWIR), the Medium Infra-Red (2.5 μm to 4.5 μm, MIR). Little use is made of Thermal Infra-Red (until 14.5 μm, TIR).

In theory, converting radiance to reflectance allows measuring the temporal variation in energy at each wavelength and in each Earth surface cell, and measuring the temporal variation of energy difference between two independent cells in each wavelength.

Due to its large number of channel and its high spatial resolution, Landsat-5 TM (launched 1985) was often used to map fire-altered vegetation in southern Europe, that is the site of very frequent and small-sized agricultural and wildfires. With the launch in 1999 of ETM+, the successor of TM onboard Landsat-7, the temporal gap for V-NIR-SWIR-TIR observations decreased from 16 to 8 days, and the number of cloud-free archived images obviously grew.

Considering a uniform Lambertian surface, and a cloudless atmosphere, and neglecting the fraction of Sun radiation backscattered upwards by the atmosphere before it reaches the Earth surface, the surface reflectance ρ is related to the at-sensor radiance L_{sen} by the following equation :

$$\rho = \pi \, (L_{sen,} - L_p)/[d^2 \, T_v \, (T_z \, E_0 \cos(\theta_z) + E_d)]$$

$$d = 1 \, / \, \{1-0.016729 * \cos\,[0.9856\,(DOY-4)]\} \, ,$$

where DOY=Day of the Year, L_p is the path radiance, E_d the downwards irradiance, E_0 the exo-atmospheric solar irradiance and θ_z is the solar zenith angle.

Radiance L_p can be evaluated by use of the so-called Dark Object Subtraction (DOS), which relies upon the hypothesis that some ground features – as some types of rocks and soils – behave as almost perfect “black bodies”. In such cases, associated reflectance measured at-satellite is almost entirely due to scattered path reflectance.

Atmospheric radiative transfer codes (*Lowtran*, *Modtran*, *Code-6S*, etc.) make use of standard atmosphere models, or of available measures of vertical atmosphere profiles, for the determination of down irradiance E_d. Finally, the accuracy of atmospheric corrections for Rayleigh scattering and aerosol effects strictly depend upon the availability of data on atmospheric physical and chemical parameters at the precise time of the remote sensing image acquisition.

B. *Mapping Burn Scars*

Many approaches at mapping BS in mid-to-high-resolution, multi-spectral spaceborne data were based on the analysis of individual scenes by means of Principal Component analysis, band ratios, vegetation indexes, unsupervised or supervised classification clustering.

However, one scene does not allow alone distinguishing properly BS from areas de-vegetated for any other reasons, as urban areas and rock outcrops, e.g. [7-9].

Multi-temporal methods based on the evaluation of qualitative changes of the spectral answer between NIR and SWIR channels seem appropriate, since fire is an agent of land cover alteration. It is accepted, therefore, that change detection reduces the likelihood of confusing BS and non-vegetated or sparsely vegetated static land cover types, urban areas, water surfaces, and rock outcrops.

In literature, multi-temporal analysis are typically associated to a combination of Principal Component Analysis followed by maximum likelihood classification [7], or to systematic searches for band ratios or index changes [5, 6, 9].

However, reflectance variation from pre-fire to post-fire is strictly related to the vegetation type and the biomass content originally present. If only changes in reflectance response are accounted for, there can be further confusing trade-off between changes due to fire damage, and changes due to hydric stress or to seasonal vegetation features.

III. MYME2 – CHARACTERISTICS OF THE METHOD

A. *The method*

In MYME2, NIR and SWIR radiances in N images acquired by any of the spaceborne platform SPOT-4/HRVIR, SPOT-5/HRG, Landsat-5/TM, Landsat-7/ETM+ or Terra/ASTER (or a combination of them), are transformed in reflectance. The exo-atmospheric solar irradiances and the Sun zenith angles are duly accounted for, while Dark Object Subtraction is used to evaluate the path radiance L_p.

In case of multi-temporal analysis, the key is to distinguish reflectance changes originated by illumination and atmospheric conditions, sensor drift or sensor differences and reflectance changes due to decrease in biomass content, chlorophyll absorption, water content and density in the vegetation cover.

A method to separate changes due to intrinsic reflectance value of vegetation from changes due to other factors influencing the at-satellite reflectance, is that of identifying pseudo-invariant features to be used as reference targets in different scenes. Such invariants must behave as Permanent Reflectors (PRs) ideally in three or more infrared bands.

MYME2 selects the pixels presenting a decrease in biomass content and chlorophyll absorption from acquired data of the multi-spectral image N-1 and the multi-spectral image N. This decrease in vegetation cover is defined taking previously defined PRs as the internal references. After automatically locating over the N-th image all non-vegetated pixels, pixels selected in both steps are considered to be fire damaged.

An example of the behaving of MYME2 is represented in Figures 1-3, where the N-1 scene is SPOT-4/HRVIR and the scene N is Landsat-7/ETM+.

B. *The characteristics*

MYME2 presents the following basic characteristics:

a) it is independent of the payload (works with Landsat5-TM, Landsat7-ETM, SPOT4 HRVIR-1 &2, ASTER, that can be used alone or in combination with each other)
b) it is highly independent of atmospheric corrections
c) it is unaffected by clouds and cloud shadows in pre-fire images
d) it is independent of the initial land cover classes of damaged vegetation.

With respect to traditional, Index-based processes, MYME2 presents the advantage of being suitable

e) for both inter-annual and intra-annual mapping
f) for winter fire mapping if intra-summer images are available
g) for estimate of damage level and, therefore, for estimate of vegetation growth rates within burnt areas.
h) for highly automated end-to-end processing (automation excludes only geo-referencing and cloud masking in post-fire images, if required).

IV. VALIDATION, ROAD TESTS AND CONCLUSIONS

Following a demonstration activity on burn scar mapping of summer 2000-2001 fires in three test-areas in Italy, aimed to provide supporting evidence to the use of spaceborne remote sensing in enforcing the Italian national law on forest fire fighting, the technique was successfully used in summer 2003 for the evaluation of post-fire erosion and solid transport hazard.

Blind tests carried out in 2001 and 2002 were aimed to demonstrate the method performances and to prospect technical concepts before moving to very-high resolution BS mapping. The statistics reported in Table 1 were obtained by screen-to-screen analysis of polygons (BS) automatically mapped by MYME2 on three sets composed of 3 standard Landsat scenes each (Landsat-5, Landsat-7 or both).

Overall, MYME2 underwent the following BS road tests:

- TM/ETM+ on eastern Sicily, Italy, 1995-2002
- TM/ETM+ on southern Italy, 1998-2002
- ETM+ on Tuscany, 1998-2001, summer and winter fires
- TM on central and southern Italy, 2003-2004
- TM/ETM+ on Corsica (France), 2003
- SPOT-4 on eastern Sicily, 2001
- ASTER on eastern Sicily, 2001, and southern Italy, 2002-2004

Based the successful processing of ca. 120 high resolution TM, ETM+ HRVIR and ASTER scenes, MYME2 was tested and validated by major, technical end-Users as: the Italian Department of Civil Protection (2001), the Italian National Firemen Corps (2002-2004), the Italian Ministry of the Environment (2003) and the French Securité Civile of the Ministry of the Interior.

We may conclude that the technique underlying the MYME2 process is robust enough to enter operational activity.

Figure 1: MYME2 step1: location of pixels presenting a decrease in vegetation cover from image N-1(SPOT, 7 June 2001) to image N (L7 ETM+, 29 July 2001)

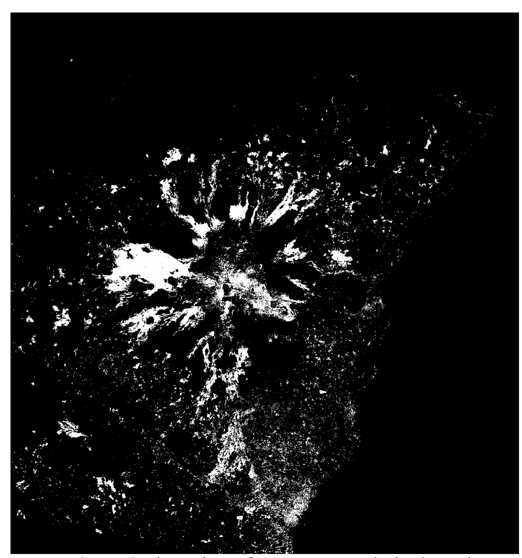

Figure2: MYME2 step2: detection of non-vegetated pixels on image N (L7 ETM+, 29 July 2001)


Figure 3: Location of the whole of pixels selected in MYME2, steps 1-2

Landsat frames #	Polygons mapped by MYME2	% Polygons validated
192-030	101	0.921
188-033	410	0.913
188-034	695	0.885

Table 1: Statistics of MYME2 results vs. screen-to-screen validation

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